

Comparison of 1980 Lake Huron, Georgian Bay - North Channel surveillance data with historical data

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Keywords: Lake Huron, Georgian Bay-North Channel, regionalization, statistically significant

Abstract

A statistical regionalization procedure was used to delineate significantly ($p \geq 0.10$) different areas, for a variety of surveillance parameters measured in 1980 in Lake Huron and Georgian Bay-North Channel. The analyses performed were compared with similar analyses done on 1971 (Lake Huron) and 1974 (Georgian Bay-North Channel) data. The regions produced from the 1980 analyses compared favourably with the 1971 and 1974 analyses. Significant ($p \geq 0.01$) increases in $\text{NO}_3\text{NO}_2\text{-N}$ and RSiO_2 were observed for Lake Huron between the 1971 and 1980 data sets. Significant ($p \geq 0.01$) increases in $\text{NO}_3\text{NO}_2\text{-N}$ and significant ($p \geq 0.01$) decreases in TP and chlorophyll *a* were observed for Georgian Bay-North Channel between the 1974 and 1980 data sets.

Introduction

In the 1972 Great Lakes Water Quality Agreement, signed by the governments of Canada and the United States, the International Joint Commission (I.J.C.) was given the mandate to establish the Upper Lakes Reference Group (U.L.R.G.). One of the study items of the Reference Group was the investigation of open water pollution on degradation of Lake Superior and Lake Huron. Surveys of the Upper Lakes were conducted to establish baseline or reference levels of various physical, chemical and biological parameters with which future water quality could be compared.

The Reference Group concluded from its studies of 1971 and 1974 data on Lake Huron, and 1974 data on Georgian Bay-North Channel (U.L.R.G., 1976, 1977a, b) that Lake Huron and Georgian Bay-North Channel were oligotrophic in nature but that man's impact was clearly evident. Phosphorus loadings restrictions were recommended to ensure that the water quality of Lake Huron was maintained at its present high level and to preserve

and protect all existing and future uses of the aquatic resource (U.L.R.G., 1977a, b).

Based on the assumption that the Upper Great Lakes were changing slowly in response to cultural and environmental impacts, the Great Lakes Water Quality Board recommended that they be sampled intensively once ever nine years (I.J.C., 1976). The nine year cycle proposed provided for both annual and intensive efforts. Annual efforts were restricted to define the magnitude and areal extent of point source pollutants, while the intensive efforts were designed to provide data in areas that responded to remedial efforts more slowly through time (e.g. open lake). An intensive open lake study was conducted on Lake Huron, Georgian Bay-North Channel (Fig. 1) in 1980. The present study uses a model (El-Shaarawi & Kwiatkowski, 1977) to study selected parameters measured in 1980. Statistical regions displaying spatial and temporal homogeneity were established for Lake Huron, and Georgian Bay-North Channel with the 1980 data set. The regions obtained were then compared to the 1971 Lake Huron and 1974 Georgian Bay-North Chan-

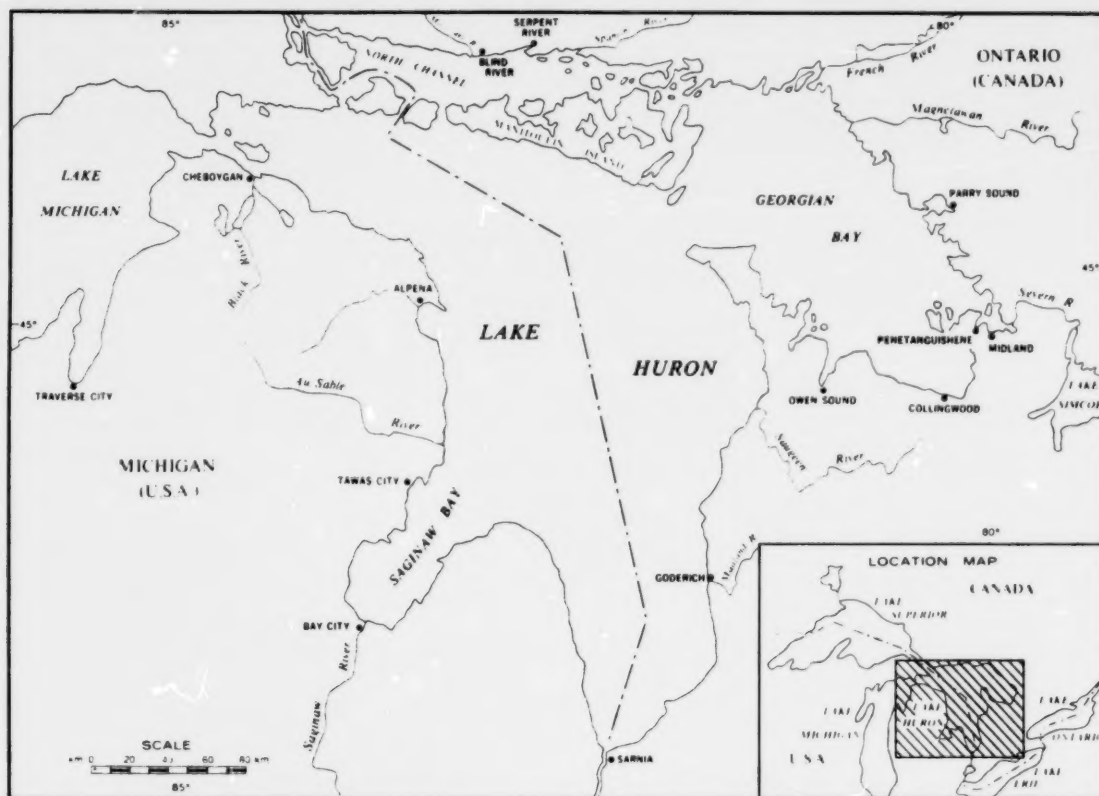


Fig. 1. Study location, Lake Huron and Georgian Bay-North Channel.

nel data (Kwiatkowski, 1980) to establish if any significant changes to the open waters had occurred.

Materials and methods

The open lake component of the intensive study on Lake Huron, Georgian Bay-North Channel represented a co-ordinated study between the Canadian Federal and U.S. Federal Governments. Each country was responsible for three of the six whole lake cruises. For the sake of quality control, each country was responsible for a particular set of parameters, independent of which research ship (Canadian or U.S.) was used. The data for the parameters discussed in this report were collected by Canadian personnel using the same instrumentation at all 138 stations on all six cruises. Table 1

Table 1. Cruise dates for Lake Huron, Georgian Bay-North Channel for 1971, 1974 and 1980.

Lake Huron 1971	Georgian Bay- North Channel 1974	Lake Huron, Georgian Bay-North Channel 1980
Apr. 19-28	Apr. 28-May 2	Apr. 13-26
May 17-25	May 18-23	May 9-22
June 15-28	June 18-22	May 28-June 7
July 19-27	July 28-Aug. 2	July 18-30
Aug. 23-30	Sept. 1-5	Sept. 8-24
Sept. 27-Oct. 4	Oct. 6-11	Oct. 20-Nov. 1
Oct. 27-Nov. 3		
Dec. 11-12		

gives the dates the cruises were conducted while Fig. 2 gives the station locations. It should be noted that the 1971 and 1974 data referred to in this presentation were also collected by Canadian personnel using identical methodologies (Kwiatkowski,

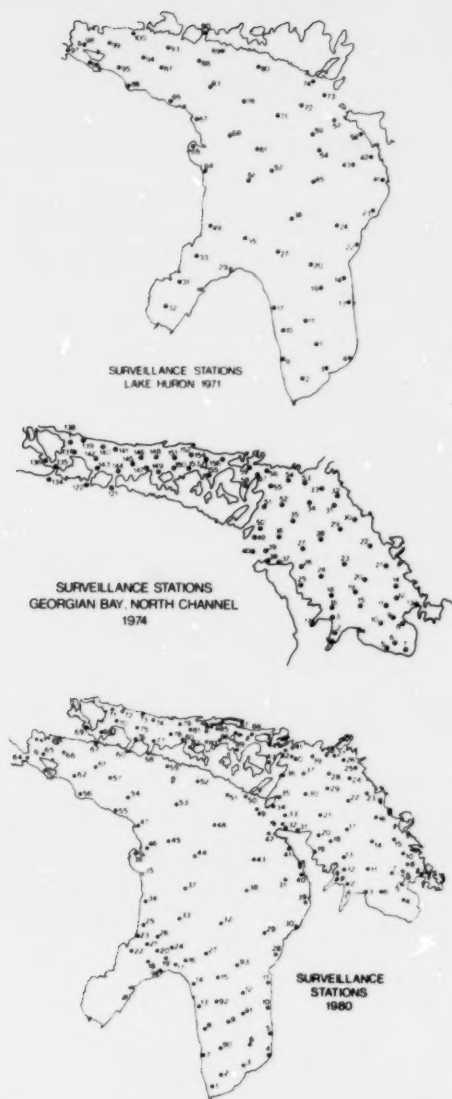


Fig. 2. Station locations for surveillance programme on Lake Huron (1971 and 1980) and Georgian Bay-North Channel (1974 and 1980).

ki, 1980).

All samples were collected from the windward side of the ship. Total phosphorus (TP), nitrate + nitrite nitrogen ($\text{NO}_3\text{NO}_2\text{-N}$), and soluble reactive silica (RSiO_2) samples were collected with a Van Dorn Bottle at various discrete depths. To reduce the complexity of the analyses, only the sample

values from the 1 m depth were used in the model runs. The $\text{NO}_3\text{NO}_2\text{-N}$ and RSiO_2 samples were filtered through a $0.45\ \mu\text{m}$ Millipore filter and analyzed on board ship by an AutoAnalyzer (Philbert & Traversy, 1973) immediately after collection. TP samples were filtered, acidified, and stored at 4°C until returned to the laboratories at CCIW for analyses (Shiomi & Kuntz, 1973). At all stations a temperature profile was obtained by bathythermograph. In the present study, only the values reported for the 1 m depth were used.

Chlorophyll *a* samples were obtained with a 0–20 m integrator (Schroeder, 1969). The method of Strickland and Parsons (1972) was used for chlorophyll extraction. The samples were also analyzed for pheopigments (pheophytin *a* plus pheophorbide *a*) using the analytical procedure described by Lorenzen (1967) and Yentsch (1970).

The surveillance data was subjected to a regression model developed by El-Shaarawi & Kwiatkowski (1977) which divides the lake into statistically homogenous regions. The model transforms the original observations, so that the transformed values approximately satisfy the assumptions required for the application of the analysis of variance: i.e., the mean value can be expressed as a linear combination of the influencing factors; constancy of variance, additivity of the error term, and normality of distribution. An additive linear model with seasonal and spatial components was then fitted to the transformed data. A hierarchical classification procedure using estimates of spatial effects is then applied to divide the lake into statistically homogeneous zones. Application of the model on a variety of biological and chemical parameters was done by El-Shaarawi & Kwiatkowski (1977) for Lake Ontario, and by Kwiatkowski (1980) for the Upper Great Lakes (Superior, Huron and Georgian Bay-North Channel). In the present study, as in the previous study done by Kwiatkowski (1980), the model was used to establish zones which were significantly different from one another at the 10% level ($p \geq 0.10$). The 1980 data was compared to the 1974 (Georgian Bay) and 1971 (Lake Huron) data sets on a zone by zone, and on a whole lakes basis with a Student T test.

Table 2. Variance ratios for the cruises and stations for the studied parameters.

Parameter	Variability between cruises (F1)	Variability between stations (F2)
Temperature	1354.89*	2.60*
NO ₃ NO ₂ -N	124.16*	8.82*
RSiO ₂	222.32*	19.13*
TP	43.96*	3.19*
Chlorophyll <i>a</i>	112.01*	1.84*

* Significant at $p \geq 0.01$.

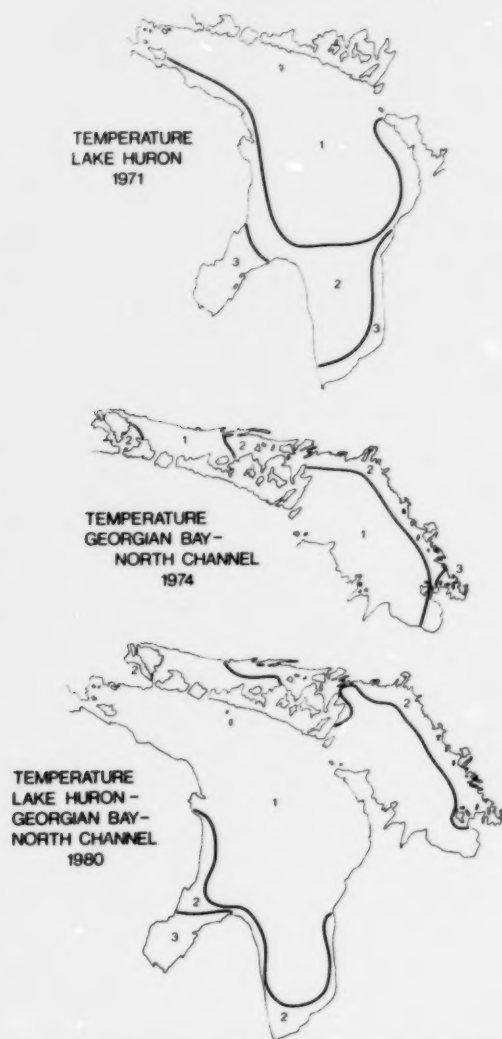


Fig. 3. Regionalization produced by model for Temperature.

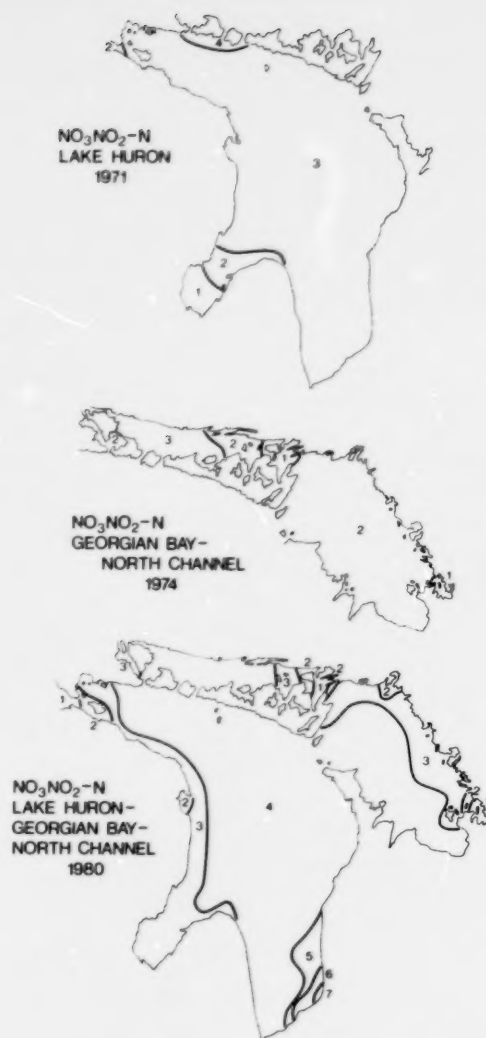


Fig. 4. Regionalization produced by model for NO₃NO₂-N.

Results

The variance ratios obtained from the model are given in Table 2 for each of the parameters studied. Significant ($p \geq 0.01$) temporal F(1) and spatial F(2) differences existed, with the temporal variability being much more pronounced (12 to 500 times) than the spatial variability. Similar findings were obtained by Kwiatkowski (1980) for Lake Superior, Lake Huron, and Georgian Bay-North Channel, and by El-Shaarawi & Kwiatkowski (1977) for

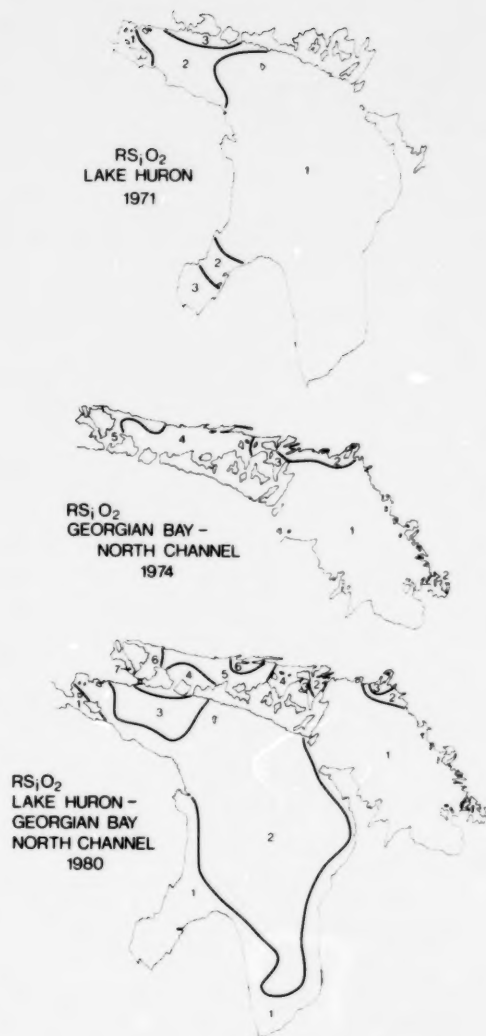


Fig. 5. Regionalization produced by model for $RSiO_2$.

Lake Ontario.

The zonations developed from the model, for each parameter studied, are given in Figs. 3-7. For comparative purposes the zonation maps obtained with the 1971 and 1974 data, for the same parameters, utilizing the same statistical procedure, are also presented in Figs. 3-7 (Data from Kwiatkowski, 1980). The number of samples obtained, the mean, the standard deviation, and the coefficient of variation, for each zone, for each parameter studied

in 1980, are given in Table 3. From the zonation maps it is apparent that Georgian Bay displays virtually identical zonation for both time periods (1980 and 1974) for four of the five parameters studied, with the exception being NO_3NO_2-N . Georgian Bay continues to be dominated by a single homogeneous zone with the exceptions of the Penetanguishene-Midland and the French River areas, where significantly higher ($p \geq 0.10$) $RSiO_2$, TP, and chlorophyll *a* concentrations are found (Figs. 5, 6 and 7). In the present study, as found with the

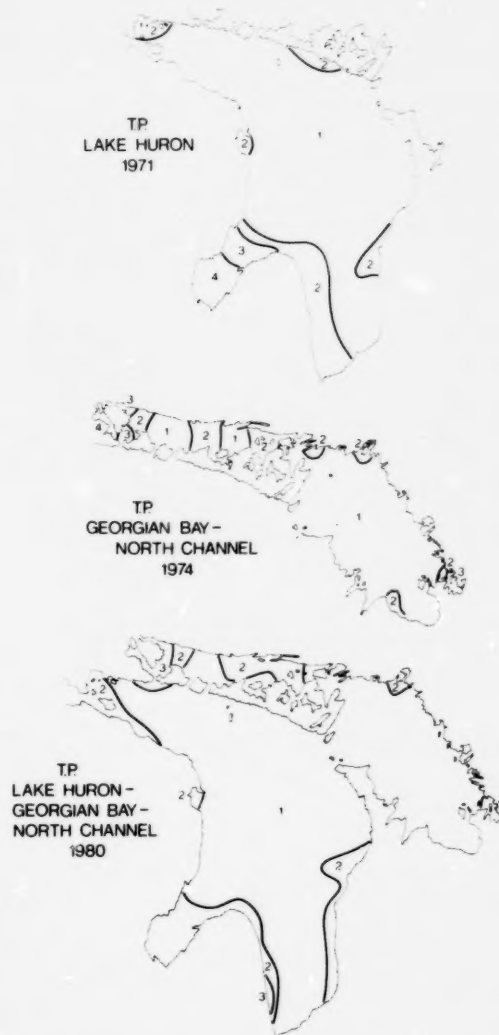


Fig. 6. Regionalization produced by model for TP.

Table 3. Zone means, standard deviations, number of observations, and coefficients of variation for the parameters studied for Lake Huron, Georgian Bay-North Channel 1980.

Parameter	Zone	Number of observations (N)	Standard deviation (SD)	Mean (x)	Coefficient of variation (CV)
Temperature °C	1	553	6.33	9.31	68.0
	2	241	5.94	11.33	52.4
	3	6	5.76	12.43	46.3
	Whole lake	800	6.27	9.94	63.1
NO ₃ NO ₂ -N mgN l ⁻¹	1	23	0.0237	0.1839	12.9
	2	23	0.0307	0.2137	14.4
	3	196	0.0276	0.2453	11.3
	4	534	0.0236	0.2698	8.7
	5	18	0.0526	0.2952	17.8
	6	12	0.1608	0.3756	42.8
	7	6	0.1713	0.4205	40.7
	Whole lake	812	0.0439	0.2631	16.7
RSiO ₂ mg SiO ₂ l ⁻¹	1	401	0.207	1.073	19.3
	2	237	0.265	1.272	20.8
	3	36	0.330	1.413	23.4
	4	51	0.196	1.649	11.9
	5	53	0.277	1.812	15.3
	6	28	0.317	1.967	16.1
	7	6	0.048	2.152	2.2
	Whole lake	812	0.358	1.269	28.2
TP mgP l ⁻¹	1	629	0.0013	0.0045	28.9
	2	158	0.0018	0.0058	31.0
	3	24	0.0023	0.0080	28.8
	Whole lake	811	0.0017	0.0048	35.4
Chlorophyll <i>a</i> µg l ⁻¹	1	655	0.536	1.398	38.3
	2	111	0.761	1.875	40.6
	3	34	2.397	2.738	87.5
	Whole lake	800	0.813	1.455	55.9



Fig. 7. Regionalization produced by model for Chlorophyll *a*.

1974 data set, the lowest yearly mean concentration of $\text{NO}_3\text{NO}_2\text{-N}$ occurred in the Penetanguishene-Midland area (Fig. 4). The North Channel continues to be a highly variable system. Concentrations of parameters TP and RSiO_2 decreased from the St. Mary's River to central Georgian Bay by more than 50%.

Lake Huron is still dominated by a large central homogeneous area. The north-south differences in water quality have become even greater in 1980, as

in comparison to 1971. Higher concentrations of TP and RSiO_2 continue to enter northern Lake Huron from the St. Mary's River, and the North Channel. Significantly ($p \geq 0.10$) lower concentrations of RSiO_2 and $\text{NO}_3\text{NO}_2\text{-N}$ flow into Lake Huron from Lake Michigan. $\text{NO}_3\text{NO}_2\text{-N}$ concentrations are 40% higher in the main lake (zone 4) as compared to that coming in from Lake Michigan (zone 1, Fig. 4). Even greater nearshore versus offshore differences are noted in 1980 versus 1971, especially in southern Lake Huron. Saginaw Bay continues to greatly influence southern Lake Huron as it did in 1971. However, the effects of the Sarnia-Goderich area on the water quality in southern Lake Huron can now be noted, especially with respect to $\text{NO}_3\text{NO}_2\text{-N}$, chlorophyll *a* and to a lesser extent with TP.

It should be pointed out that the actual concentration values in any given zone are not constant from year to year. The statistical model is applied to one year's data at a time. Therefore in order to determine if concentrations in a given area have increased or decreased with time, the 1980 zonation maps obtained in the present study were superimposed on to the 1971 Lake Huron and 1974 Georgian Bay-North Channel data sets. The number of samples obtained, the mean and the standard deviation for the 1980 zonation on Georgian Bay-North Channel (1980 and 1974) and Lake Huron (1980 and 1971) data sets are given in Table 4. The differences obtained between the 1974-1980 (Georgian Bay-North Channel) and the 1971-1980 (Lake Huron), are expressed as percentages, increased or decreased, in Table 5. RSiO_2 , TP and chlorophyll *a* concentrations were from 2 to 13% lower in 1980 versus 1974, on a whole lake basis, for Georgian Bay-North Channel; however only the TP and chlorophyll *a* decreases were significant ($p \geq 0.01$). All the $\text{NO}_3\text{NO}_2\text{-N}$ zones established for Georgian Bay-North Channel displayed significant increases with an overall lake increase of 10.4%. The parameters RSiO_2 and $\text{NO}_3\text{NO}_2\text{-N}$ were significantly ($p \geq 0.01$) higher on a whole lake basis, in 1980 versus 1971, (2 to 24%) for Lake Huron. The largest differences were found in the southern portion of Lake Huron where increases of 25 to 73% occurred in $\text{NO}_3\text{NO}_2\text{-N}$ concentrations. TP values increased by 4.3% on a whole lake basis, while chlorophyll *a* decreased by 8.5%. Neither change was significant at the 5% level.

Table 4. Comparison of zone means ($\bar{x}$), standard deviations (SD), and number of observations (N) between 1971, 1974 and 1980, Lake Huron, Georgian Bay North Channel utilizing the 1980 zonation.

Parameter	Zone	Georgian Bay North Channel 1980			Lake Huron 1980			Georgian Bay North Channel 1974			Lake Huron* 1971		
		N	SD	$\bar{x}$	N	SD	$\bar{x}$	N	SD	$\bar{x}$	N	SD	$\bar{x}$
Temperature °C	1	238	6.03	9.55	315	6.55	9.13	287	6.54	10.49	377	5.03	11.15
	2	133	5.37	11.23	108	6.59	11.45	142	6.08	11.91	101	5.03	13.37
	3				6	5.76	12.43				10	6.01	14.45
	Whole lake	371	5.85	10.16	429	6.62	9.76	429	6.42	10.96	488	5.13	11.68
NO ₃ NO ₂ -N mg N l ⁻¹	1	17	0.0202	0.1825	6	0.0337	0.1880	16	0.0292	0.1638	8	0.0398	0.1731
	2	11	0.0248	0.2147	12	0.0363	0.2127	11	0.0295	0.1830	24	0.0430	0.1863
	3	112	0.0239	0.2444	84	0.0321	0.2466	112	0.0252	0.2172	72	0.0461	0.2050
	4	243	0.0206	0.2675	291	0.0258	0.2717	289	0.0265	0.2426	307	0.0327	0.2208
	5				18	0.0526	0.2952				16	0.0656	0.2347
	6				12	0.0160	0.3756				8	0.0651	0.2300
	7				6	0.1713	0.4205				8	0.0763	0.2431
	Whole lake	383	0.0297	0.2555	429	0.0526	0.2699	428	0.0325	0.2315	443	0.0407	0.2166
RSiO ₂ mg SiO ₂ l ⁻¹	1	222	0.154	1.081	179	0.258	1.062	264	0.225	1.107	143	0.323	0.962
	2	29	0.336	1.266	208	0.255	1.273	29	0.414	1.288	252	0.282	1.085
	3	12	0.436	1.444	24	0.273	1.398	5	0.324	1.448	48	0.291	1.243
	4	33	0.191	1.661	18	0.209	1.628	44	0.310	1.757	7	0.233	1.469
	5	53	0.277	1.812				50	0.355	1.967			
	6	28	0.317	1.967				31	0.315	2.020			
	7	6	0.048	2.152				6	0.060	2.267			
	Whole lake	383	0.408	1.339	429	0.292	1.207	429	0.465	1.372	451	0.311	1.069
Tp mg P l ⁻¹	1	302	0.0011	0.0043	327	0.0015	0.0046	350	0.0023	0.0051	322	0.0114	0.0044
	2	63	0.0019	0.0057	95	0.0018	0.0058	62	0.0022	0.0059	118	0.0177	0.0056
	3	18	0.0020	0.0081	6	0.0034	0.0079	17	0.0028	0.0091	8	0.0092	0.0070
	Whole lake	383	0.0016	0.0047	428	0.0017	0.0049	429	0.0024	0.0054	448	0.0134	0.0047
Chlorophyll <i>a</i> µg l ⁻¹	1	332	0.398	1.228	323	0.636	1.414	376	0.488	1.384	269	0.612	1.505
	2	41	0.515	1.788	70	0.873	1.926	32	0.723	1.869	22	2.215	2.382
	3	5	0.485	2.500	29	2.594	2.779	6	1.812	2.950	30	2.860	3.397
	Whole lake	378	0.468	1.306	422	1.011	1.593	414	0.587	1.443	321	1.307	1.741

* Stations 31 and 32 are not included in the computations.

Table 5. Differences, as percentages, between historical Lake Huron, Georgian Bay North Channel data and 1980 data.

Parameter	Zone	Georgian Bay North Channel 1974 vs 1980	Lake Huron 1971 vs 1980
Temperature °C	1	9.0	18.1**
	2	5.7	14.4*
	3		14.0
	Whole lake	7.3	16.4**
NO ₃ NO ₂ -N mgN l ⁻¹	1	11.4*	8.6
	2	17.3*	14.2
	3	12.5**	20.3**
	4	10.3**	23.1**
	5		25.8**
	6		63.3*
	7		73.0*
	Whole lake	10.4**	24.6**
RSiO ₂ mgSiO ₂ l ⁻¹	1	2.3	10.4**
	2	1.7	17.3**
	3	0.3	12.5*
	4	5.5	10.8
	5	7.9*	
	6	2.6	
	7	5.1**	
	Whole lake	2.4	12.9**
TP mgP l ⁻¹	1	15.7**	4.5
	2	3.3	3.6
	3	11.0	12.9
	Whole lake	13.0**	4.3
Chlorophyll <i>a</i> µg l ⁻¹	1	11.3**	6.0
	2	4.3	19.1
	3	15.3	18.2
	Whole lake	9.5**	8.5

* Significant at $p \geq 0.05$.

** Significant at $p \geq 0.01$.

Discussion

The water chemistry of Lake Huron and Georgian Bay-North Channel is determined by basin geology and inputs (from Lake Superior and Lake Michigan, from the atmosphere, and from anthropogenic sources). Surveillance of the water quality, to ensure compliance with federal pollution source regulation, in Lake Huron and Georgian Bay-North Channel is vital for the determination of the most practical means of protecting this irreplaceable resource. One of the major underlying concepts for the management of water quality is that of non-degradation. The IJC's Great Lakes Water Quality Board designed a surveillance plan for

Lake Huron and Georgian Bay-North Channel to provide data to characterize the chemical, physical and biological components of the aquatic ecosystem against which future changes could be evaluated; quantify cause (loads) and effect (water quality) relationships; and to compare present data with data collected in the past in order to determine if there have been changes and how these changes may be occurring. The first and second components of the plan have been adequately addressed by the Upper Lakes Reference Group (1976, 1977a, 1977b). The present paper is an attempt to supply information on the third component: Has there been any change in the water quality of Lake Huron and Georgian Bay-North Channel between 1971 and 1980?

Statistically significant differences exist between offshore and nearshore areas for large lakes (Kwiatkowski, 1978). Nearshore areas are the recipient of all tributary, point source and diffuse source inputs, which can undergo coastal entrapment due to different current patterns inshore versus offshore (Csandy, 1970). The water quality of Lake Huron and Georgian Bay-North Channel continues to be characterized by a large offshore area of low concentrations of both the chemical and biological parameters measured. This is comparable to the findings on Lake Superior (Kwiatkowski 1980) and in contrast to analysis done on Lake Ontario by El-Shaarawi & Kwiatkowski (1977) which indicated that large nearshore areas of significantly higher concentrations exist. Nearshore regions in the present study were spatially intermittent and localized around point sources as previously described by Kwiatkowski (1980).

It is difficult to characterize the water chemistry of the North Channel. Inflows from the Serpent, Mississagi, and Spanish rivers and Lake Superior, via the St. Mary's river, constitute approximately 46% of the channel's volume (U.L.R.G., 1977b). Movement of RSiO₂ and TP from the North Channel to Lake Huron is evident from the regionalization maps (Figs 5 and 6), while NO₃NO₂-N and chlorophyll *a* values remain relatively homogeneous (Figs. 4 and 7). The exchange of Georgian Bay water with Lake Huron and the North Channel is considerable, but highly variable. As a result of these influences, the water chemistry of different parts of the bay can be characteristic of the bay itself, or resemble Lake Huron or the North Chan-

nel (U.L.R.G., 1977b). The Penetanguishene-Midland and the French River were the point source areas resulting in localized areas of higher concentrations in Georgian Bay. With the exception of RSiO_2 there were no significant ($p \geq 0.10$) differences between the open lake water masses of Georgian Bay and Lake Huron. Water mass exchanges due to current movements between basins assures rapid mixing and therefore homogenous distribution of the studied parameters. This is not the case, however, for the northern portion of Lake Huron, which acts as a mixing area for the inputs from Lake Michigan and Lake Superior. This is clearly evident in the regionalization map for RSiO_2 (Fig. 5). Traditionally high silicate values have been reported for Lake Superior, while low values have been found in Lake Michigan. These differences are attributable to the differences in basin geology of the two lakes and to the larger diatom population in Lake Michigan removing silicates from the water (U.L.R.G., 1977b). In this study, the average concentration of RSiO_2 flowing into the North Channel from the St. Mary's river (Lake Superior) was 2.15 mg l^{-1} while the average concentration flowing into northern Lake Huron from Lake Michigan was 0.91 mg l^{-1} . The central portion of Lake Huron continues to be dominated by a large homogeneous region for all the studied parameters. Significant nearshore-offshore differences become more pronounced in southern Lake Huron. The summer pattern for Lake Huron epilimnial currents (U.L.R.G., 1977b) indicates that movement is down the west shore (across the mouth of Saginaw Bay) and up the east shore. As can be seen in the regionalization maps the areal extent of the surface concentrations for all parameters studied are greatly influenced by this epilimnial current. Sixty percent of the U.S. urban population in the Lake Huron basin can be found in the Saginaw Bay area. Concentrations of TP and chlorophyll *a* in Saginaw Bay can be $10 \times$ greater than that found in central Lake Huron (Smith *et al.*, 1977; Bierman & Dolan, 1980; Kwiatkowski, 1980). These high concentrations influence the water quality on the U.S. side of southern Lake Huron. It is interesting to note that significantly ($p \geq 0.10$) higher concentrations of all parameters studied now show nearshore-offshore differences on the Canadian side of southern Lake Huron, especially with respect to $\text{NO}_3\text{NO}_2\text{-N}$ and chlorophyll *a*. Though chlorophyll *a* measurements

are not direct measures of algal biomass (Dolan *et al.*, 1978), higher concentrations of this parameter found in conjunction with higher concentrations of TP and $\text{NO}_3\text{NO}_2\text{-N}$ are indicative of a higher trophic condition nearshore versus offshore.

Temporal variabilities (F1) being 10 to 600 times greater than the spatial variabilities (F2, Table 2) are not unusual for the Great Lakes (El-Shaarawi & Kwiatkowski, 1977; Kwiatkowski, 1980). Inputs, currents, thermal changes and biological interactions result in large seasonal fluctuations in the water quality of the Great Lakes. In lieu of the fact that only six cruises were conducted, discussions on seasonal patterns will not be attempted. The F1, F2 values obtained in the present study are very similar to the ones obtained by Kwiatkowski (1980) for Georgian Bay-North Channel 1974.

The concept of doing intensive sampling on Lake Huron and Georgian Bay-North Channel once every nine years would seem appropriate for the open-lake area. However, nearshore areas should be monitored on a more frequent basis. On a whole lake basis for Georgian Bay-North Channel, decreases of 2 to 13% were found for RSiO_2 , TP and chlorophyll *a* between 1974 and 1980. In Lake Huron, RSiO_2 and TP concentrations were slightly higher in 1980 versus 1971 (13 and 12%) and chlorophyll *a* was slightly lower (8.5%). The parameter showing the largest change over the study period was $\text{NO}_3\text{NO}_2\text{-N}$. In Georgian Bay-North Channel the increase in concentration between 1974 and 1980 was fairly uniform for all zones (Tables 4 and 5) and averaged out to a whole lake increase of 10.4% ($p \geq 0.01$). A large increase in $\text{NO}_3\text{NO}_2\text{-N}$ concentrations were found in the 1980 zones 5, 6 and 7, located on the Canadian side of southern Lake Huron (26, 63 and 73%). It should be kept in mind that this study is comparing only two data sets (1971 and 1980) and thus the concept of decreasing or increasing trends is meaningless without more data points. However on the lower Great Lakes, annual measurements have been taken over the last 10 to 15 years and statistically significant ($p \geq 0.05$) increasing trends in $\text{NO}_3\text{NO}_2\text{-N}$ have been reported for Lake Erie (Fraser, DOE, pers. commun.), Niagara River (Kuntz & Chan, 1982) and Lake Ontario (IJC, 1980a). Annual measurements of spring $\text{NO}_3\text{NO}_2\text{-N}$ measurements in Lake Erie, Lake Ontario and the Niagara River indicate that $\text{NO}_3\text{NO}_2\text{-N}$ is increasing at a rate of approximately 10-12

$\mu\text{g l}^{-1}$ annually. The IJC (1978) attributed the increases in Lakes Erie and Ontario to either an absence of controls on nitrogen inputs or reduced uptake by declining populations of aquatic organisms. Similar processes may also be taking place in the Upper Great Lakes.

In the present study significant increases representing an annual rate of $4 \mu\text{g N l}^{-1}$ for Georgian Bay-North Channel and $6 \mu\text{g N l}^{-1}$ for Lake Huron were found. In zones 5, 6 and 7, a localized area near a highly productive rural area (U.L.R.G., 1976), where large amounts of nitrogen rich fertilizers are used, an annual increase of $10.9 \mu\text{g l}^{-1}$ was calculated. At point source areas around urban inputs, where fertilization is on a much smaller scale (i.e. Pentanguishene-Midland, French River, Spanish River, Alpena and Black River) annual increases of only $2.3 \mu\text{g l}^{-1}$ were recorded. $\text{NO}_3\text{NO}_2\text{-N}$ concentration levels in Saginaw Bay, a highly urbanized area, have not shown any increases over the past decade (Dolan, pers. commun.) and may indeed be on a decrease. The analysis of Lake Huron data would indicate that the reported increasing trends in $\text{NO}_3\text{NO}_2\text{-N}$ are mainly a result of increased farm fertilization and a lack of controls on non-point source loadings. Obviously, further investigation of this matter is warranted before a cause-effect relationship can be established.

Large lakes such as Lake Huron, Georgian Bay-North Channel are complex both individually and as a system. In the present study small, though significant changes in the water chemistry of the open waters have occurred between 1971 and 1980. It is apparent from the large temporal variability found in all parameters studied, that it is difficult to establish cause and effect relationships. Due to the fact that each parameter and each statistical zone established in the present paper displayed a different seasonal cycle, it is mandatory that the seasonal cycle be properly defined for each zone. Continuous monitor stations should be established in each statistical zone, which are capable of taking weekly or daily samples. The concept of decreased spatial coverage with increased temporal sampling was made by Kwiatkowski (1978) for the Lake Ontario surveillance plan. Apparently the open lake water quality conditions for Lake Huron and Georgian Bay-North Channel are changing very slowly and therefore only need to be monitored once every nine years to delineate spatial heterogeneity, as outlined

in the Great Lakes International Surveillance Plan (IJC, 1980b). However, detailed annual assessment of the nearshore areas, especially for southern Lake Huron are needed. This will require coordination of the Federal surveillance programme with the Provincial and State programmes, to ensure that similar methodologies are used, and to ensure quality control. Combination of programmes, with respect to zone formation, station pattern and cruise frequency should be done to produce a truly sound (cost: information) surveillance programme. The analysis presented provides a convenient method of interpreting water quality conditions in order to distinguish the effect of remedial programmes from natural variation. By regionalizing the lake, changes on a whole lake basis, as well as, changes near to or remote from sources, can be evaluated. The method outlined can be effectively used to ascertain the nature and degree of changes in water quality of aquatic systems (whether fresh or marine), particularly those resulting from man's activities.

Acknowledgements

The author would like to thank the captains, and ships' crews of the CSS Limnos and RV Simon, and the technical and chemical operation's crew for their assistance in the collection and analyses of the samples. The 1980 data reported represents the 1980 surveillance intensive effort on Lake Huron by the Canadian and American Federal Governments. All data presented in this paper were obtained from the data files at the Canada Centre for Inland Waters, Burlington, Ontario, Canada.

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Received 3 June 1982; in revised form 20 December 1983; accepted 18 January 1984.